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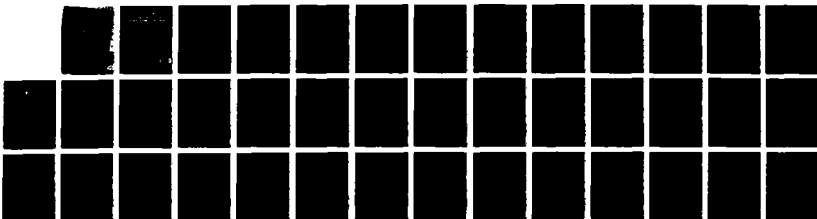
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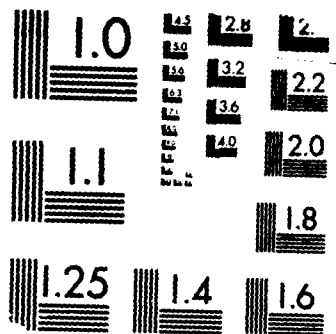
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A STUDY RELATING TO THE FOG OIL REPLACEMENT PROGRAM

**INTERIM REPORT
BFLRF No. 241**

By

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The U.S. Army has made a commitment to replace smoke generator fog oil with diesel fuel and/or JP-8. This report discusses the work done to help solve this existing fog oil substitution problem. Areas of research included: (a) modification of diesel fuel and JP-8 by removal of their lower boiling fractions. (b) design, construction, and development of a bench test for measuring obscuration. (c) running a computer-simulation program to assist in evaluating the engineering feasibility of designing, developing, and constructing a compact unit capable of fractionating diesel fuel and/or JP-8 should this be desired. (d) conducting a literature search to identify methods and/or compact equipment capable of fractionating diesel fuel and JP-8 to higher average molecular weight fractions. (e) production of test samples. (f) chemical analyses and obscurant evaluations.					
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FOREWORD

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I. BACKGROUND

Since the concept of smoke generation was developed prior to World War I, smoke has been used as an obscurant in both defensive and offensive operations.(1)* Smoke is employed in offensive operations primarily to neutralize enemy firepower and reduce mobility; for defensive operations, smoke is used to neutralize enemy observation and aimed enemy fire. Employment of obscuring smoke on an attacking armored force may cause it to reduce speed, change its direction, deploy prematurely, and/or rely on nonvisual means of command and control.(2) Smoke employment in offensive operations is primarily for neutralizing enemy firepower and reducing mobility.

Smoke employment in maneuver operations has become an automatic tactical response in the battlefield scenarios. It is inevitable that obscurants will play an increasingly important role in countering current and emerging weapon systems. Therefore, there will be an ever-increasing demand on the low-viscosity petroleum oil called Smoke Generator Fog Oil, MIL-F-12070C (NATO Code F-62) or materials capable of replacing it.

At a workshop in October 1985 on the fog oil substitution problem, it was stated that the Army had made a commitment to replace fog oil with diesel fuel.(3) The three reasons given were:

- a. Insufficient fog oil would be available to support wartime requirements
- b. Relatively expensive (approximately three times the price of diesel fuel)
- c. Logistical problems

Another important consideration regarding the fog oil replacement problem is the fact that OSHA recently ruled that products containing 0.1 percent "untreated naphthenic oils" must be labeled as carcinogenic.(4) Naphthenic oils are the principal ingredients used in making fog oil (MIL-F-12070C). A representative of a fog oil manufacturer and supplier addressed the concern that naphthenes may be carcinogenic in a 1985 paper and a company report.(5,6)

* Underscored numbers in parentheses refer to the list of references at the end of this report.

The logistical problems appear to be the dominant factor for replacing fog oil. It has been estimated that the fog oil requirements for a 30-day period of combat would exceed 400,000 drums.⁽¹⁾ This large amount of oil presents a severe logistical burden for the Army that they would like to remove. Since the vehicles that carries the pulse jet smoke generator (M3A3) have historically used diesel fuel, it would be desirable if diesel fuel could be used as a replacement for fog oil. However, there is now a trend for U.S. military vehicles used in Europe toward the use of JP-8 as a primary fuel.⁽⁷⁾ Therefore, both diesel fuel and JP-8 are now being considered as replacements for fog oil.

II. OBJECTIVE

The objective of this program is to assist the Chemical Research, Development, and Engineering Center (CRDEC) with its fog oil substitution program. This report covers the work completed since the letter report dated 30 July 1986 entitled "Status of Cooperative Belvoir/CRDEC Fog Oil Project (WD 8)."

The following research phases were addressed:

- The modification of diesel fuel and JP-8 in some manner resulting in the fuel's being as effective an obscurant as Smoke Generator Fog Oil. Samples were prepared using the semiautomatic distillation unit located in the synthetic fuel center at Southwest Research Institute (SwRI). These samples were tested by CRDEC to establish their effectiveness as a replacement of fog oil under actual field conditions. This production of these samples are described in Section III-A of this report.
- Development of a bench test for measuring obscuration and performing chemical and physical analysis as needed. Other follow-up tasks are needed as a result of the encouraging results of both the small-scale testing (5-gallon samples) and the large-scale (50-gallon samples) tests conducted by CRDEC.
- A literature search needed to determine if ways and/or means already exist for accomplishing this modification (i.e., distillation, fractionation, etc.) using much smaller and compact equipment than that used by SwRI to prepare the samples.

The equipment and method needed must be able to process 1 to 2 gallons per minute of diesel fuel and/or JP-8 and be capable of separating up to 50 percent of the feed stream. It is desirable that the equipment be compact and small enough that it can be conveniently fitted on or in the Armored Personnel Carrier (2320-968-6321) or other vehicles of choice. The literature search and the results are discussed in Section III-C.

Another possibility for obtaining the compact equipment to produce these modified fuels is for CRDEC to build it or have it built. As a preparatory step for this contingency, a computer program was used to design and size such a fractionating unit. The details of this task are discussed in Section III-D.

III. SCOPE OF WORK

A. Pilot Plant Production of Fog Oil By Distillation

Referee grade diesel fuel (MIL-F-46162) and Jet A were distilled through the pilot plant distillation unit at SwRI. Jet A was substituted for JP-8, the fuel of interest, because of its availability and because its specifications are almost identical to those of JP-8.

The two base fuels were fractionated in the following manner:

<u>Fuel</u>	<u>Overhead, vol%</u>	<u>Bottoms, vol%</u>	<u>Sample ID Number</u>
(AL-14948-F) DF-2	20	80*	AL-15418-F
(AL-14948-F) DF-2	30	70*	AL-15419-F
(AL-14948-F) DF-2	50	50*	AL-15420-F
(AL-15421-F) Jet A	25	75*	AL-15423-F
(AL-15421-F) Jet A	50	50*	AL-15422-F

*50-gal. sample removed from this fraction and shipped to Dugway, UT.

With the concurrence of CRDEC, the overhead fractions from the distillations were discarded during the distillation process in order to expedite the production and delivery of the requested bottom fractions. Thus, 50 gallons each of the bottom fractions and the base fuels were shipped via motor freight to the U.S. Army Dugway Proving Ground, Dugway, UT, for testing as obscurants.

All fractions were prepared using a 1:1 reflux ratio and a vacuum of 15 inches Hg(Abs). Each fraction that was shipped was also submitted to the laboratory for API gravity (ASTM D 1298), flash point (ASTM D 193), and simulated distillation by gas chromatography (ASTM D 2887) determinations. The results from these tests are shown in TABLE 1. The D 86 Distillation Correlation was applied to the D 2887 data from all the bottom fractions. For plotting purposes, the retention times of the gas chromatography data were replaced with the corresponding temperatures. Fig. 1 compares the two base fuels, DF-2 and Jet A, with fog oil. Fig. 2 compares the three DF-2 bottom fractions with fog oil. Fig. 3 compares the Jet A bottom fractions with fog oil. In order to compare D 2887 with D 86, one sample (AL-15418-F; 80 percent DF-2 Bottoms) also had a D 86 test run on it, and the data are included in TABLE 1. Percentages of saturates, olefins, and aromatics for the base fuels as determined by ASTM D 1319 are also included in this table.

Previously, samples of five gallons each of the bottom fractions from DF-2 were produced in a manner similar to that described above and were sent to CRDEC for evaluation. Although this work was described previously (8), it is included in Appendix A of this report for the convenience of the reader.

B. Bench-Scale Apparatus for Obscurant Evaluation

A fog-generating device for bench-scale evaluation of candidate samples was designed and built early in the program. The following requirements for this experimental test device were the basis of the design:

- (a) A fog-generating device that provides repeatable temperature profiles;
- (b) An accurate method to introduce the fog-oil candidate into the heated reaction chamber;
- (c) A method to maintain a constant dilution ratio of the smoke being generated;
- (d) A method to accurately assess the obscuration provided by the generated smoke and to provide a comparison between the various samples being tested.

This bench-test apparatus consisted of a gasoline-powered Briggs and Stratton engine fitted with an exhaust assembly. This assembly consisted of a 1-inch (2.5 cm) diameter by 11.75-inch (29.8 cm) length conduit tubing that served as the reaction chamber. This

TABLE 1. Test Results of Pilot Plant Production of Fog Oil Samples by Distillation

	AL-14948-F Base Fuel	AL-15418-F 80% Bottoms	AL-15419-F 70% Bottoms	AL-15420-F 50% Bottoms	AL-15421-F Base Fuel	AL-15423-F 75% Bottoms	AL-15422-F 50% Bottoms
• API Gravity	31.2	30.3	29.4	27.7	41.5	40.0	38.6
• Flash Point, °F (°C)	144 (62)	223 (106)	256 (124)	283 (139)	122 (50)	172 (78)	193 (89)
• ASTM D 86 Distillation, °F(°C) Correlation from ASTM D 2887 Data							
Recovery Percent							
IBP	347 (175)	443;450*	484 (252)	518 (270)	322 (162)	386 (197)	416 (214)
5	365 (185)	472;475	499 (260)	533 (279)	363 (184)	400 (205)	426 (219)
10	402 (206)	489;486	514 (268)	551 (289)	377 (192)	410 (210)	437 (225)
20	455 (235)	510;503	531 (278)	572 (300)	393 (201)	421 (217)	448 (232)
30	491 (255)	529;518	547 (287)	588 (309)	404 (207)	429 (221)	455 (235)
50	529 (127)	564;554	580 (305)	613 (323)	420 (216)	445 (230)	465 (241)
70	588 (309)	606;597	616 (325)	632 (334)	449 (232)	465 (241)	481 (250)
80	607 (320)	618;620	626 (330)	637 (337)	463 (240)	474 (246)	488 (254)
90	641 (339)	648;648	653 (345)	663 (351)	486 (253)	496 (258)	509 (265)
EP	704 (374)	711;704	715 (380)	724 (385)	534 (279)	547 (287)	563 (295)
• ASTM D 1319							
Saturates, %	36.0	--	--	--	78.8	--	--
Olefins, %	1.3	--	--	--	1.1	--	--
Aromatics, %	62.6	--	--	--	20.1	--	--

* All data in this column are from ASTM D 86 procedure.

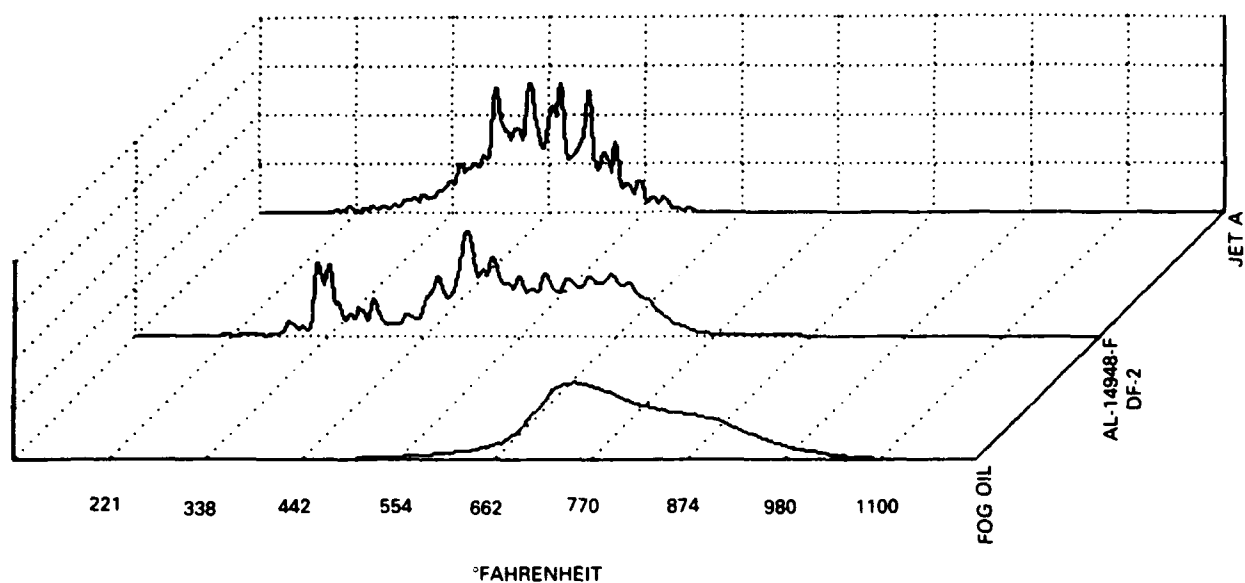


Figure 1. Fog oil, DF-2 and Jet A

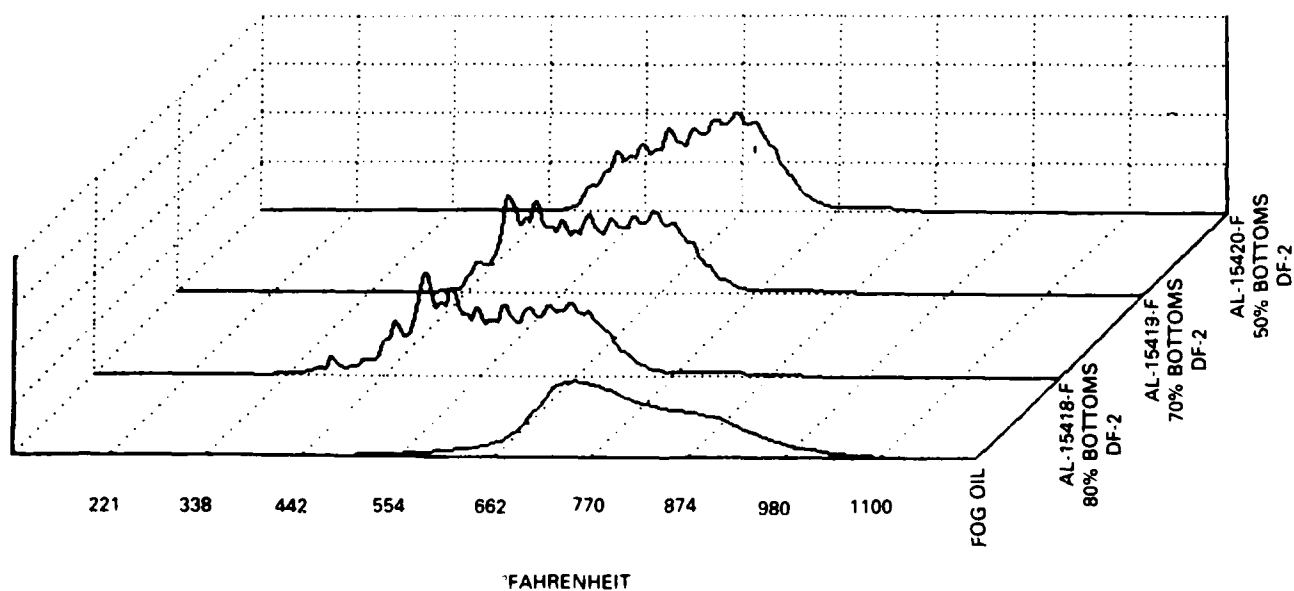


Figure 2. Fog oil, 80-percent bottoms DF-2, 70-percent bottoms DF-2, 50-percent bottoms DF-2

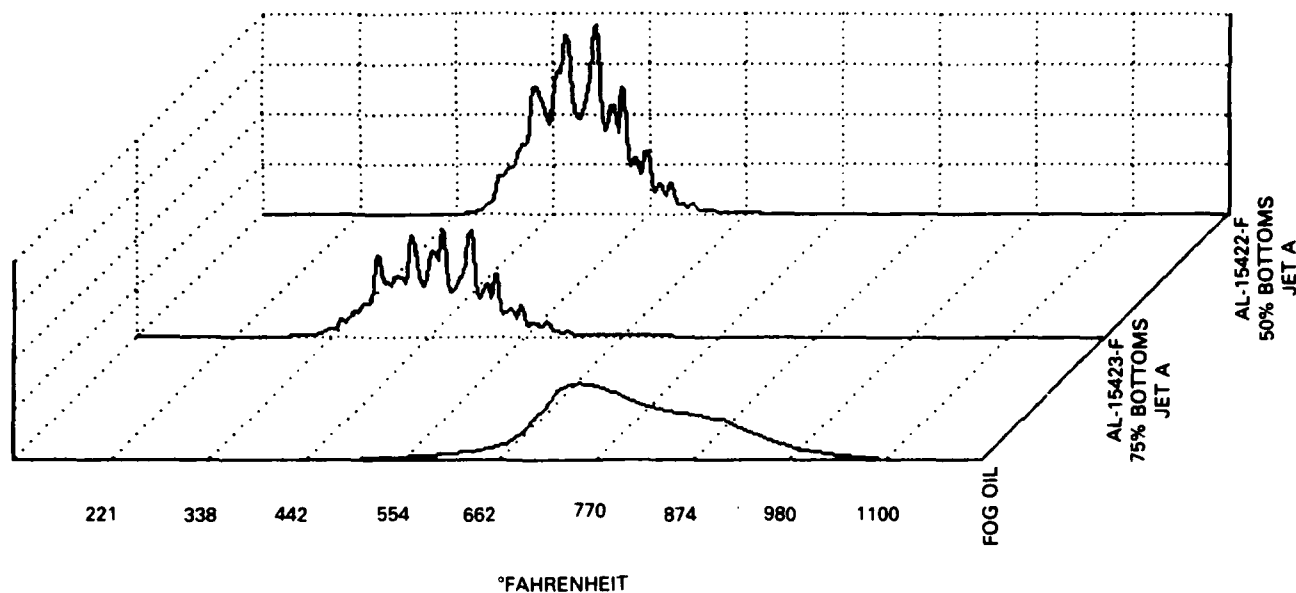


Figure 3. Fog oil, 75-percent bottoms Jet A, 50-percent bottoms Jet A

reaction chamber discharged into a 14-inch (35.6 cm) diameter by 10-foot (3.05 m) length of piping. The engine was operated at approximately 960 rpm, and the temperature of the exhaust gases was measured at four thermocouple positions.

A generator placed a load on the engine for temperature and speed control. A positive displacement pump was used to feed the fog oil sample at a constant flow of 6 mL per minute into the hot engine exhaust for vaporization. The temperature of the engine exhaust during sample vaporization was found to be $283^{\circ} \pm 7^{\circ}\text{C}$. An exhaust fan assists the smoke (fog) that is generated to flow past a photo cell at a relatively constant rate. A profile map of the air velocity at the end of the reaction chamber (near the photo cell) was made in order to duplicate the test conditions at another location if moved. The obscuration is measured with the photo cell attached to a strip recorder. The experimental set up is shown in Fig. 4.

Recently obscurant evaluations were made on samples received from CRDEC using the above described fog oil bench test apparatus. The samples were compared to fog oil, and

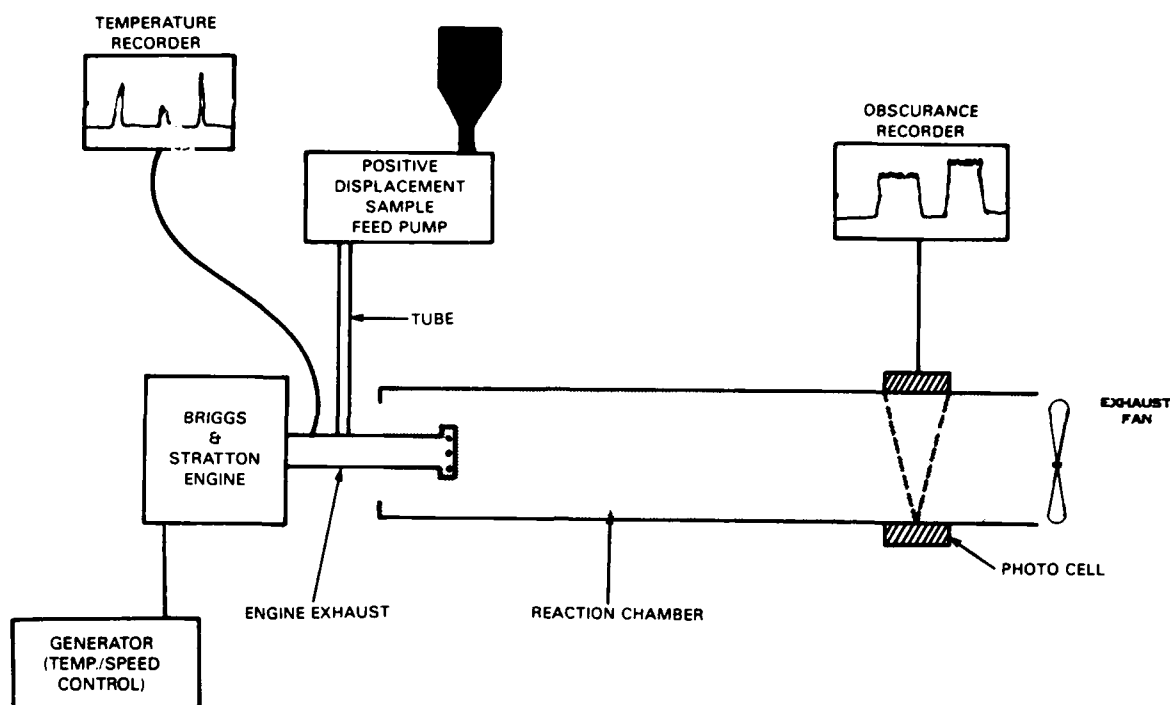


Figure 4. Simplified schematic of fog generating device

the results of the tests were normalized (fog oil = 100). The normalized rating of these samples are listed below:

Fog Oil (AL-15119-F)	100
75-Percent Bottoms, DF-2 (AL-14932-F)	97
Diesel Fuel	83
75-Percent Bottoms, Jet A-1	21
Jet A-1	0

Laboratory analyses were also made on these samples, including determination for boiling range distribution by gas chromatography (ASTM D 2887), flash point (D 93), viscosity (D 445), carbon and hydrogen (D 3178), density (D 1298), and polynuclear aromatic hydrocarbons. The results of these laboratory analyses are listed in TABLE 2.

TABLE 2. Test Results of Samples Supplied by CRDEC

	Phillips Referee Base Fuel, DF-2 (Control Lot G-075)		Turbine Jet A-1 Base Fuel		75% Bottoms of DF-2 (AL-14932-F)		75% Bottoms of Jet A (AL-15423-F)		Fog Oil (AL-15119-F)	
ASTM D 2887										
Boiling Range Distribution of Petroleum Fractions by Gas Chromatography, oC (oF)										
Recovery Percent										
IBP	131 (267)	150 (302)	199 (390)	167 (333)	222 (432)					
5	184 (364)	167 (333)	241 (465)	187 (369)	304 (579)					
10	203 (397)	174 (346)	255 (491)	197 (386)	328 (622)					
20	223 (434)	184 (363)	270 (518)	206 (403)	347 (657)					
30	239 (463)	193 (379)	283 (541)	216 (420)	359 (678)					
50	268 (514)	208 (407)	312 (594)	233 (452)	384 (723)					
70	298 (568)	224 (435)	342 (647)	253 (487)	417 (783)					
80	314 (598)	235 (455)	354 (669)	262 (503)	436 (817)					
90	336 (637)	247 (477)	368 (695)	275 (527)	460 (860)					
EP	400 (752)	285 (545)	452 (845)	326 (618)	524 (975)					
Flash Point (ASTM D 93), oC (oF)										
	74 (166)	63 (145)	116 (240)	78 (172)	163 (325)					
Viscosity (ASTM D 445), cSt										
40oC (104oF)	2.51	1.40	5.21	1.75	19.60					
100oC (212oF)	1.08	0.71	1.70	0.84	3.64					
Carbon/Hydrogen Ratio (ASTM D 3178)										
% C	86.65	85.91	86.42	86.20	86.92					
% H	12.93	13.76	12.81	13.47	12.77					
Density (ASTM D 1298) at 15oC (59oF)	0.8481	0.8138	0.8770	0.8249	0.8994					
Polynuclear Aromatic Hydrocarbons by U.V.										
Mono-aromatics, %	12.2	10.7	9.3	9.1	9.1					
Di-aromatics, %	6.8	2.2	6.0	5.2	3.9					
Tri-aromatics, %	0.92	0.14	0.75	0.13	1.4					

C. Literature Search

A literature search was conducted to identify methods and/or compact equipment capable of fractionating diesel fuel and JP-8 to higher average molecular weight fractions. The search consisted of two parts: (1) machine search (computer) and (2) manual search.

1. Computer Search

The computer search was intentionally made broad in order not to miss any pertinent information, thereby resulting in a large volume of material to examine further. Patents and foreign language papers were not excluded. Three data bases were chosen for this search. The data bases were Chemical Abstracts, NTIS, and Compendex. A detailed description of the search is included in Appendix B. After examining the pertinent references found, it was noted that a very few might be adaptable, but only with extensive modifications and costs. No methods, processes, or "off-the-shelf" equipment were found in the literature search that could be used directly for fractionating diesel fuel and JP-8 to higher average boiling fractions.

2. Manual Search

The manual search consisted of identifying manufacturers of distillation, evaporation, and vaporization equipment, followed by inquiries via telephone. Many of the companies offered to do contracted studies to design and build the needed equipment. Several companies sent literature on equipment that is available. Copies of this literature were forwarded to CRDEC.

The conclusion drawn from the telephone survey is that an "off-the-shelf" item that would be small enough in size and still have a sufficient output to meet the requirements of a smoke generator or a pair of smoke generators is not available at this time. Additional details of this search and a list of the companies contacted can be found in Appendix B.

D. Computer Simulation

A computer simulation program was run to assist CRDEC in evaluating the engineering feasibility of designing, developing, and constructing a compact unit capable of fractionating diesel fuel and/or JP-8 should this option be chosen. The Process Simulation Program is a comprehensive simulation system available through an SwRI contract. This program combines a large chemical component library and thermodynamic properties methods with unit operations prediction techniques to handle mass and energy balance calculations. The program uses the most extensive, advanced, and flexible prediction methods and calculation techniques available in industry.

The problem stated was for the diesel fuel case. After sketching the process flow diagram (Fig. 5) and defining the problem and the type of data desired in the solution, all the known applicable information (stream property data, unit component operations, thermodynamic data, etc.) were input into the program. The letters that were used in the flow diagram corresponds with those used in the computer simulation. The process system consists of a tank for the feed stock (FS), a feed pump (P1), two heat exchangers (HX1 and HX2), a flash heater (HXF), a flash drum (F1), a pump for product delivery (P2) and a pump for the removal of the overhead fraction (P3). The pressures and flow rates of the various components and streams were arbitrarily set and entered. Basically, the only experimental data entered were the ASTM D 86 and specific gravity data of the starting diesel fuel (Stream 1). Other data, such as molecular weight, thermodynamic data, etc. that is needed to arrive at a solution were calculated by the program using correlations and the entered data.

The program as written separates each individual stream into 19 smaller streams (true boiling point cuts) with each stream being treated discretely. These 19 streams and their properties and compositions can be found in TABLE 3.

The program was then run and a solution obtained. TABLE 4 gives a summary of the conditions of the heat exchangers, HX1, HX2, and HXF. Additional data on these units, including heating and cooling curves, were provided but not included here.

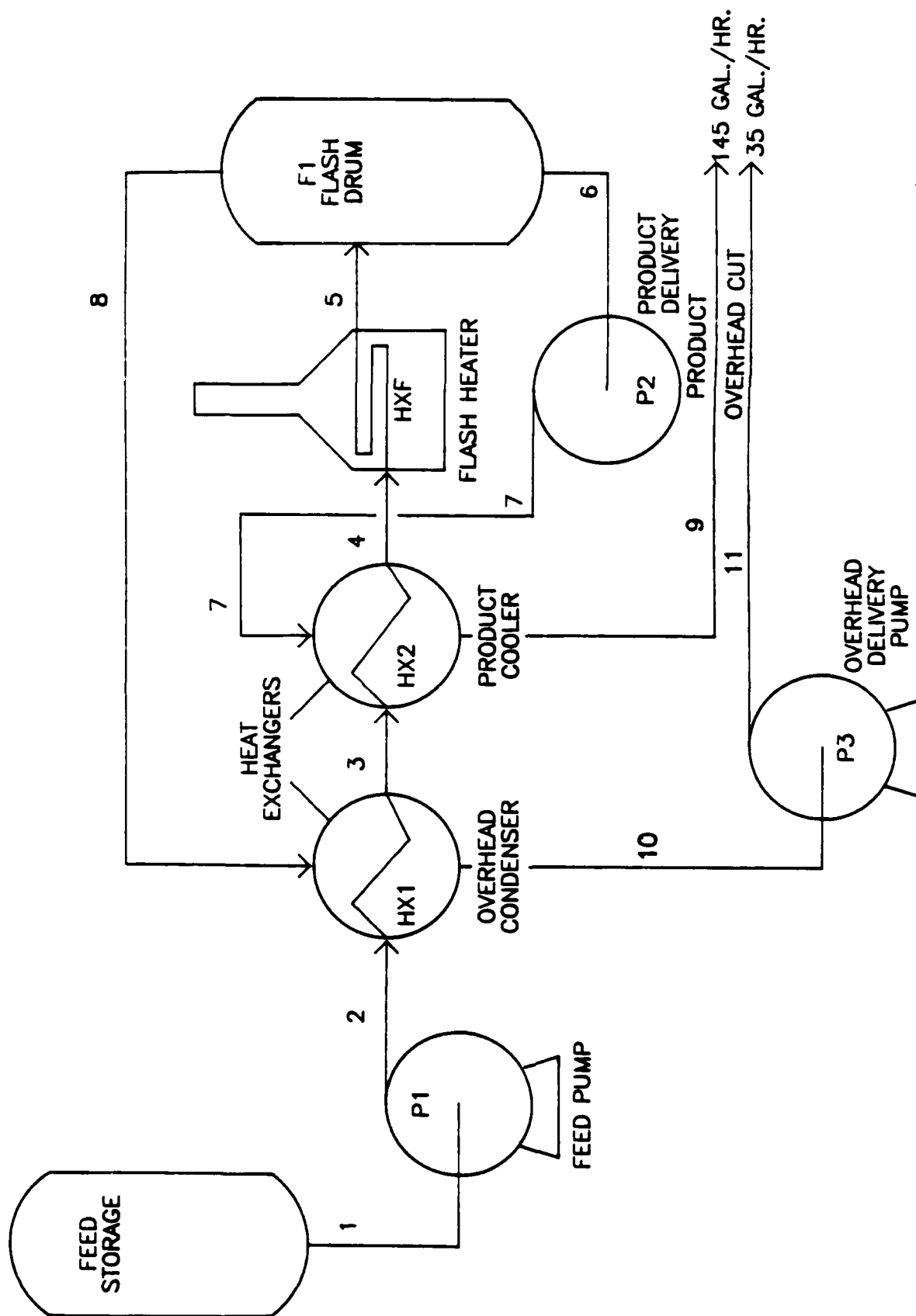


Figure 5. Process flow diagram for fog oil problem

TABLE 3. Feed Stream (1) Component Breakdown to 19 Smaller Streams and Their Calculated Composition and Properties

Component	Normal Boiling Point, °F(°C)	Liquid Volume, %	gals/hr	lb/hr	moles/hr	Molecular Weight	API Gravity	Specific Gravity	Critical Pressure, P _c , psig	Critical Temp., T _c , °F	Critical Volume, V _c , cc/gmole	Compressibility Factor, z
1	288 (143)	1.85	3.33	23	0.215	105.38	41.84	0.8163	448.96	637.04	413.42	0.2609
2	312 (156)	4.49	4.75	33	0.263	123.70	40.74	0.8216	429.15	663.10	439.09	0.2591
3	338 (170)	7.61	5.62	39	0.293	132.19	39.70	0.8265	408.67	689.20	467.73	0.2573
4	362 (184)	12.72	9.20	64	0.453	140.86	38.60	0.8319	390.11	714.09	496.53	0.2556
5	387 (198)	17.49	8.58	60	0.399	150.28	37.31	0.8382	372.24	739.80	527.42	0.2540
6	412 (212)	21.91	7.95	56	0.349	160.44	36.05	0.8445	354.35	765.50	561.15	0.2523
7	437 (225)	26.82	8.85	63	0.366	171.03	34.84	0.8507	337.03	790.52	596.98	0.2507
8	462 (239)	32.54	10.30	73	0.404	182.10	33.67	0.8567	320.21	815.10	635.26	0.2491
9	487 (253)	39.17	11.93	86	0.442	193.82	32.65	0.8620	303.27	839.05	667.29	0.2475
10	512 (267)	47.02	14.13	102	0.496	205.63	31.53	0.8679	287.87	862.65	720.19	0.2460
11	538 (282)	54.62	13.68	98	0.455	218.68	30.59	0.8730	271.51	886.39	769.81	0.2443
12	559 (293)	67.25	22.74	166	0.724	229.54	29.74	0.8776	259.16	905.82	811.72	0.2430
13	587 (309)	73.06	10.45	77	0.314	244.48	28.68	0.8834	243.28	931.16	871.22	0.2412
14	613 (323)	77.91	8.73	65	0.249	259.10	27.86	0.8879	228.76	954.04	931.67	0.2395
15	637 (337)	85.07	12.89	96	0.353	272.23	26.76	0.8941	217.51	975.98	985.67	0.2380
16	661 (350)	91.17	10.99	83	0.290	285.10	25.33	0.9022	207.94	998.97	1038.00	0.2365
17	687 (364)	95.60	7.97	60	0.202	299.03	24.06	0.9096	197.92	1022.09	1096.51	0.2349
18	712 (378)	99.23	6.52	50	0.159	313.73	23.00	0.9159	187.79	1044.50	1160.05	0.2331
19	737 (392)	100.00	1.39	11	0.032	329.13	22.39	0.9195	177.44	1064.64	1228.98	0.2312
Totals	--	--	180.00	1305	6.456	--	--	--	--	--	--	--
Average	--	--	--	--	--	201.95	31.20	0.8697	--	--	--	--

**TABLE 4. Summary of the Conditions of the Heat Exchange Units
HX1, HX2, and HXF**

	Heat Exchangers		
	HX1	HX2	HXF
<u>Operating Conditions</u>			
Btu/hr	87,730	177,990	101,790
Low Mean Temp. Diff., °F(°C)	150.6(66)	68.4(21)	--
Area, sq. ft	23.31	216.70	--
<u>Hot Side Conditions</u>			
Inlet Stream No.	8	7	--
Physical State	Vapor	Liquid	--
Stream Temp., °F(°C)	529.3(277)	529.5(277)	--
Stream Press, psig	15.0	40.0	--
lb moles/hr	1.558	4.898	--
lb/hr	252.0	1051.8	--
C _p , Btu/lb-°F	0.5806	0.6606	--
Outlet Stream No.	10	9	--
Physical State	Liquid	Liquid	--
Stream Temp., °F(°C)	90.7(33)	241.7(117)	--
Stream Press, psig	5.0	35.0	--
lb moles/hr	1.558	4.898	--
lb/hr	252.0	1051.8	--
C _p , Btu/lb-°F	0.4377	0.5131	--
<u>Cold Side Conditions</u>			
Inlet Stream No.	2	3	4
Physical State	Liquid	Liquid	Liquid
Stream Temp., °F(°C)	40.67(5)	191.7(89)	438.5(226)
Stream Press, psig	53.6	48.6	43.6
lb moles/hr	6.456	6.456	6.456
lb/hr	1303.8	1303.8	1303.8
C _p , Btu/lb-°F	0.4024	0.4878	0.6150
Outlet Stream No.	3	4	5
Physical State	Liquid	Liquid	Liquid
Stream Temp., °F(°C)	191.7(89)	438.5(226)	557.2(292)
Stream Press, psig	48.6	43.6	38.6
lb moles/hr	6.456	6.456	6.456
lb/hr	1303.8	1303.8	1303.8
C _p , Btu/lb-°F	0.4878	0.6150	0.7104

There are three pumps included in the system as designed. They are:

- P-1 Feed pump
- P-2 Product delivery pump
- P-3 Overhead - Delivery pump

A summary of the data generated concerning these three pumps, based on the input data and the conditions necessary to arrive at a solution to the problem, is included in TABLE 5. As with the heat exchangers, additional data on these pumps were provided but not included here.

TABLE 5. Summary of Pump Units

	<u>Pump P3</u>		<u>Pump P2</u>		<u>Pump P1</u>	
Work, HP	0.13		0.07		0.02	
Efficiency, %	65.0		65.0		65.0	
	<u>Inlet</u>	<u>Outlet</u>	<u>Inlet</u>	<u>Outlet</u>	<u>Inlet</u>	<u>Outlet</u>
Stream No.	1	2	6	7	10	11
Temperature, °F(°C)	40.0(5)	40.7(5)	529.3(277)	529.5(277)	90.7(33)	91.1(33)
Pressure, psig	5.0	53.6	15.0	40.0	5.0	40.0
Head, ft	—	128.1	—	84.4	—	96.7
Hot Volume, gal./hr	178.5	178.4	184.5	184.3	36.2	36.2

The program as run generated D 86 distillation curves for both the product stream 9 and the overhead cut 11. In addition to the ASTM D 86 data, it also predicted API gravities and molecular weights for each of the D 86 fractions. These data can be found in TABLE 6, and also plotted for visual inspection as Figs. 6 through 8.

A stream summary of the eleven major streams is shown in TABLE 7.

TABLE 6. Distillation Data (D 86), API Gravities, and Molecular Weights
for the Product Stream (9) and Overhead Stream (11)

Liquid Volume, %	Product Stream (9)			Overhead Stream (11)		
	ASTM D 86, oF(°C)	Gravity, oAPI	Mol. Wt., lb/mole	ASTM D 86, oF(°C)	Gravity, oAPI	Mol. Wt., lb/mole
Initial Boiling Point	360.6 (183)	41.61	108.8	340.8 (172)	41.84	105.4
5.0	403.0 (207)	38.84	139.0	343.9 (174)	41.53	110.4
10.0	428.4 (221)	36.91	153.5	351.7 (178)	40.75	123.4
30.0	508.7 (265)	32.20	198.6	381.7 (195)	38.47	141.8
50.0	545.1 (286)	30.03	225.8	414.5 (213)	35.95	161.3
70.0	589.5 (310)	27.92	258.0	466.5 (242)	32.89	191.1
90.0	647.5 (342)	24.44	294.9	536.2 (281)	29.65	230.8
95.0	669.5 (355)	23.39	308.3	567.7 (298)	28.24	252.3
End Point	689.1 (366)	22.71	320.9	628.1 (332)	24.62	293.3

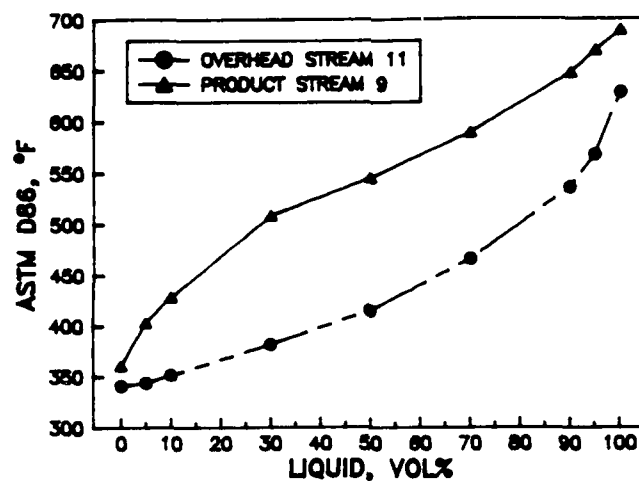


Figure 6. Property curve—ASTM D 86 distillation data

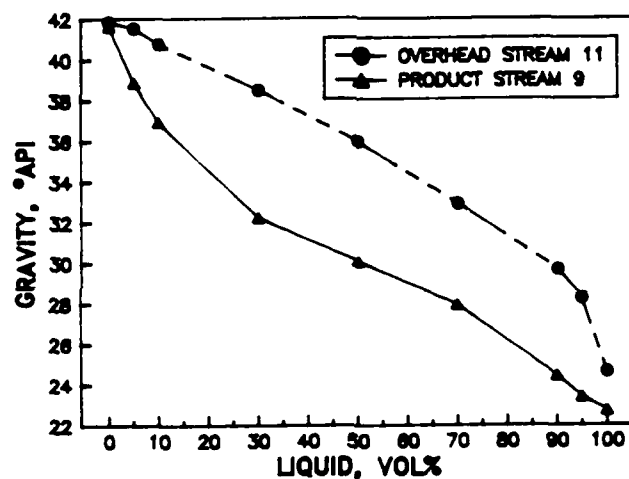


Figure 7. Property curve—API gravity versus liquid volume percent

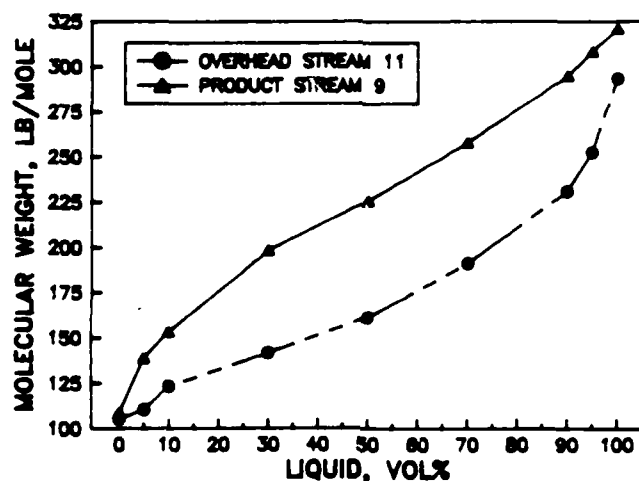


Figure 8. Property curve—molecular weight versus liquid volume percent

TABLE 7. Summary of Properties of Process Streams

Stream	Units Connected*	Physical State**	lb-Moles, hr	M, lb/hr	C _p , Btu/lb-°F	Temp, °F (°C)	Pressure, psig	Molecular Weight
1	FS-P1	Liquid	6.456	1.304	--	40.0 (4)	5.0	201.94
2	P1-HX1	Liquid	6.456	1.304	0.4024	40.7 (4)	53.6	201.94
3	HX1-HX2	Liquid	6.456	1.304	0.4878	191.7 (89)	48.6	201.94
4	HX2-HXF	Liquid	6.456	1.304	0.6150	438.5 (226)	43.6	201.94
5	HXF-F1	Liquid	6.456	1.304	0.7104	557.2 (292)	38.6	201.94
6	F1-P2	Liquid	4.898	1.052	--	529.3 (276)	15.0	214.75
7	P2-HX2	Liquid	4.898	1.052	0.8606	529.5 (276)	40.0	214.75
8	F1-H1	Vapor	1.558	0.252	0.5806	529.2 (276)	15.0	161.71
9	HX2	Liquid	4.898	1.052	0.5131	241.7 (116)	35.0	214.75
10	HX1-P3	Liquid	1.558	--	--	90.7 (33)	5.0	161.71
11	P3	Liquid	1.558	--	--	91.1 (33)	40.0	161.71

* P1 = Feed pump

P2 = Product delivery pump

P3 = Overhead delivery pump

HX1 = Heat exchanger

HX2 = Heat exchanger

HXF = Flash heater

F1 = Flash drum

FS = Feed storage

** Standard liquid conditions are 60.0°F (16°C) and 14.696 psia.
Standard vapor volume is 379.490 ft³/lb mole.

IV. RESULTS AND RECOMMENDATIONS

A. Results

- A computer simulation program indicated that a compact unit capable of fractionating diesel fuel and/or JP-8 was feasible.
- Information was obtained via a computer program on processing conditions, product composition, overhead composition, and hardware sizes.
- A bench test was designed, built, developed, and used to measure obscuration on various samples.
- Results from the bench test correlated well with the full-scale test at Dugway.
- A literature search was conducted to identify methods and/or compact equipment for fractionating diesel fuel and/or JP-8 to higher average molecular fractions. No methods, processes, or "off-the-shelf" equipment were identified that could be used directly for fractionating these fuels.
- Large samples (50 gallons each) of modified diesel fuel and JP-8 (Jet A) were produced for testing.
- Chemical analyses were performed on various samples as requested.

B. Recommendations

- Based on computer-aided design, it is recommended that consideration be given to incorporating a self-contained flash-evaporation distillation unit onto or into the M3A4 unit. This modification would result in a greatly simplified system that could be sized to the space available.
- An alternative to a portable flash evaporative system for vehicle on-board use is a larger, but somewhat less mobile unit that could supply many fog

generators with fuel from a centrally located field position. It is recommended that the computer simulation program be used to obtain data, much like that described in Section III-D, for the eventuality that this larger evaporative system might be considered. This type of large equipment would undoubtedly be commercially available but the cost may be prohibitive. In any case, the computer program could provide valuable data for studying this option.

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2. U.S. Army Training and Doctrine Command TRADOC Pamphlet 525-3: U.S. Army Operational Concept for Employment of Smoke, Fort Monroe, Virginia, 26 September 1980.
3. Workshop of Fog Oil Substitution Problem, Gainesville, Florida, 22-23 October 1985.
4. Letter from M.E. LePera, Chief, Fuels and Lubricants Division, Materials, Fuels, and Lubricants Laboratory, U.S. Army Belvoir Research and Development Center, Fort Belvoir, VA to the Commander, U.S. Army Medical, Biological Research and Development Laboratory, Fort Detrick, MD, 15 July 1985 on the subject: Health Hazards Associated with the Exposure to MIL-F-12070C Fog Oil.
5. Weinberg, D.E., "Carcinogenic Hazard Determination of Naphthenic Oils Under the OSHA Hazard Communication Regulations". Paper No. FL-85-84 presented at the 1985 Fuels and Lubricants Meeting, National Petroleum Refiners Association, Houston, TX, November 7-8, 1985.
6. Golden Bear Tech Report, "OSHA Hazard Communication Standard Hazard Determination of Golden Bear Naphthenic Oils", Golden Bear Division, Witco Chemical Corporation, Los Angeles, CA 90067.
7. Fuels and Lubricants Quarterly Bulletin, Vol. 8, No. 1, 2 December 1986, U.S. Army Belvoir Research and Development and Engineering Center, Fort Belvoir, VA.
8. Monthly Progress Report for March 1986, prepared for the U.S. Army Belvoir Research, Development and Engineering Center for the work being conducted under Contract No. DAAK70-85-C-0007, by the Belvoir Fuels and Lubricants Research Facility (SwRI).

9. Technical Manual, TM-3-1040-202-12, Generator, Smoke, Mechanical, Pulse Jet, M3A3 (NSN 1040-00-587-3618), Headquarters, Department of the Army, December/1975.

APPENDIX A
PRODUCTION OF FOG OIL BY DISTRIBUTION

Referee grade diesel fuel (MIL-F-46162) was fractionated in three passes through a semi-automatic distillation unit. The objective of this work was to distill off 25 percent overhead fractions, thereby, producing candidate fog oil as the corresponding bottom fractions:

	Bottoms Fraction as Vol% of Original Feed		
	Pass <u>1</u>	Pass <u>2</u>	Pass <u>3</u>
Experimental Design	75.0	50.0	25.0
Actual Result	75.9	57.5	26.1

In practice, bottoms from each pass became distillation unit feedstock for the subsequent pass (after removing 5 gallons of later fog oil evaluation). °API gravity and D 86 distillation data for the various samples are attached as TABLE A-1.

TABLE A-1. Production of Fog Oil by Distillation

	Pass No.			
	0 (Diesel Fuel)	1	2	3
Reflux Ratio		1:1	2:1	2:1
Vacuum, inches Hg (abs.)		0.5	0.5	0.3
<u>Overhead Fraction</u>				
Sample No.	---	AL-14931-F	AL-14934-F	AL-14945-F
<u>Test Results</u>				
● °API Gravity	---	34.5	34.7	31.1
● D 86 Distillation				
IBP, °F	---	302	381	474
10%	---	336	431	519
30%	---	352	462	535
50%	---	372	479	547
70%	---	410	493	562
90%	---	486	517	591
EP, °F	---	587	556	619
<u>Bottoms Fraction</u>				
Sample No.	AL-14619-F (Tank #31)	AL-14932-F	AL-14935-F	AL-14946-F
<u>Test Results</u>				
● °API Gravity	30.4	29.5	27.8	24.8
● D-86 Distillation				
IBP, °F	334	474	534	610
10%	396	511	560	626
30%	492	538	576	635
50%	542	570	599	643
70%	591	606	623	654
90%	644	651	659	678
EP, °F	687	701	695	728

APPENDIX B
LITERATURE SEARCH - DETAILED INFORMATION

1. Computer Search - The three data bases used in this search are:

- a. Chemical Abstracts - This data base covers over 12,000 journals of the chemical sciences literature, patents from 26 countries, new books, conference proceedings, and government research reports.
- b. NTIS (National Technical Information Service) - This data base contains citations of government-sponsored research and development from over 240 federal agencies. The file is broad and cross-disciplinary in areas of major technical interest.
- c. COMPENDEX - This file corresponds to Engineering Index Monthly. This data base covers almost all of the engineering fields, including petroleum, mechanical, and automotive engineering.

A similar search strategy was used in all the searches and is illustrated by the following example using the Chemical Abstracts Data Base:

<u>Item No.</u>	<u>Term Used</u>		<u>Number of Hits</u>
1	Distillation	Group A	4402
2	Evaporation		5266
3	Vaporization		2295
4	Flash	Group B	4985
5	One Plate		2
6	Portable		955
7	Pilot Plant		1351
8	Pilot Seal		279
9	Mobile		1998
10	Items 1-3		10996
11	Items 4-9		9511
12	Items 10 and 11		370

A "hit" is defined here as a reference found containing the word or words being search. The total hits from item 12 indicate that 370 references have been identified containing at least one term from Group A (Items 1 through 3) and at least one term from Group B

(Items 4 through 9). The citations for the references and the abstracts (when available) of the hits in the final step were printed out.

Table B-1 shows the number of hits in the final steps for the three data bases searched.

Table B-1. Results of the Literature Search

<u>Data Base</u>	<u>Period Covered</u>	<u>Hits in Final Step</u>
Chemical Abstracts	1967-1987	370
NTIS	1970-1987	152
COMPENDEX	1970-1987	161

Since the search strategy was to have broad coverage, the likelihood that any important material was missed is almost nil. However, as a result of this approach, much of the material identified (hits) was extraneous on such diversified subjects as waste water treatment, radioactive waste, concentration of liquids in processing plants, deposition of thin films using flash evaporation, etc.

Printed abstracts of references identified (hits) were available off-line from both the NTIS and COMPENDEX data bases. The American Chemical Society that operates Chemical Abstracts does not, as a matter of policy, have abstracts available via the computer data base. However, computer searching of this data base does give other information such as title, author(s), citation, Chemical Abstract (CA) number, location of work, etc. The CA number is important since it facilitates the finding of the abstract in the "hard copy" of Chemical Abstracts. In searching the Chemical Abstracts data base, the titles were carefully examined for indications of their possible value on the targeted subjects. The CA numbers of those titles that appeared to have merit, even marginal, were noted and used to locate the printed abstract in the respective volume of Chemical Abstracts. The abstracts from all three data bases were then carefully scrutinized. A large number of these abstracts were related to desalination, including many patents. The more promising of these references were obtained for further study,

since it might be possible to adapt their concept to the higher boiling range of diesel fuel and/or JP-8. A list of these papers and patents are included below.

Anon, "Will New High Gravity Technology Obsolete Toll Distillation Towers?," Industrial Chemical News, January 1983.

Arlidge, D.B., "Wiped Film Evaporators as Pilot Plants," Chemical Engineering Progress, pp. 35-40, August 1983.

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Garg, S.K. and Datta, R.L., "Design of a Shipborne Flash Distillation Unit of a Sea Water Desalination Plant," Indian Chem. J., 4(1), p. 57, 1969.

Gupta, A.K., "Portable Distillation Unit," Chemical ERA, November 1976.

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Kane, A.S., Mehta, D.J. and Chandorikas, M.V., "Design of Plate Type Reverse Osmosis Plant for Desalination," Indian Chem. J., 4(1), p. 55, 1969.

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Lazet, F.J., "Apparatus for Liquid Separator by Flash Distillation," U.S. Patent 3,713,990, Assignor to Philadelphia Quartz Co., Philadelphia, PA, Patented 30 January 1973.

Loeffler, H.H., "Portable Water Distiller," U.S. Patent 4,342,623, Assignor to Arthur D. Little, Inc., Cambridge, MA, Patented 3 August 1982.

Malewar, C.S. and Shah, C.M., "Flash Distillation Process--Design Innovations for the Flash Chamber," Chemical Engineering World, Vol. XII, No. 4, p. 47, 1977.

Marovich, F.A., Bordeaux, J. and Sawtella, D.W., "Portable Distillation Unit," U.S. Patent 3,694,321, Assignor to the United States of America as represented by the Secretary of the Army, Patented 28 September 1972.

Miyatake, O., Tomimura, T., Ide, Y. and Fujii, T., "An Experimental Study of Spray Flash Evaporation," *Desalination*, 36(2), p. 113, 1981.

Murphy, M., "Gravity-Defying Process Could Reshape Refining Technology," *The Oil Daily*, 4 October 1984.

O'Sullivan, D., "Novel Separation Technology May Supplant Distillation Towers," *Chemical and Engineering News*, 7 March 1983.

Pritchard, C., "Distillation With Vapor Compression. An Undergraduate Experimental Facility," *Chem-Eng-Educ.*, 20(3), p. 132, 1986.

Roe, R.C. and Othmer, D.F., "Controlled Flash Evaporation," *Chemical Engineering Progress*, Vol. 67, No. 7, p. 77, 1971.

Sharathan, D., "Method and Apparatus for Flash Evaporation of Liquids," U.S. Patent Appl. U.S. 471,392, 17 August 1984, NTIS Order No. PAT-APPL-6-471-392.

Shelton, R.E., "Vacuum Desalinization Device," U.S. Patent 4,584,061, Patented 22 April 1986.

Tidball, R.A., "Flash Distillation Apparatus and Method," U.S. Patent 3,697,385, Assignors to Aerojet-General Corporation, El Monte, California, Patented 10 October 1972.

U.S. Department of the Interior, Office of Saline Water, "Skid-Mounted Flash Distillation Pilot Plant," *Distillation Digest Volumes 1 and 2*, Research and Development Report 538, March 1970.

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Wangnick, K., "Selection of Small Desalination Plants for Specific Locations--Reverse Osmosis, Flash Distillation, Vapour Compression," *Desalination*, 52, p. 145, 1985.

Weiss, S., "Portable Water Distillation Apparatus," U.S. Patent No. 4,081,331, Patented 28 March 1978.

Williamson, W.R., "Horizontal Cylindrical Distillation Apparatus," U.S. Patent 4,148,693, Patented 10 April 1979.

2. Manual Search

The three main sources for locating the manufacturers of distillation, evaporation, and vaporization equipment were:

1. **CEC 87**
Chemical Engineering Catalog
Reinhold Publishing
Division of Penton Publishing
600 Summer Street
P.O. Box 1361
Stanford, CT 06904
2. **Hydrocarbon Processing Catalog**
Published and Printed by Hydrocarbon Processing
Gulf Publishing Company
Box 2608
Houston, TX 77001
3. **Thomas Register of American Manufacturers
and Thomas Register Catalog File**
Thomas Publishing Company
One Penn Plaza
New York, NY 10001

TABLE B-2 lists the companies contacted by telephone. The problem was explained to their technical representative, along with the requirements that the equipment must meet, such as distillation rates (flow rate of product), cut-point temperature, space requirement, etc. The question was then posed as to whether an "off-the-shelf" item was available to meet these needs. No unit was found that could satisfy all the requirements, although several companies refrained from giving a categorical "no" and asked for additional information about the apparatus desired. Many of the questions could not be answered at that time because the information was not available. These questions covered items such as sizes of the heat exchangers, pumps, power supply, etc. Much of this needed information is now available as the result of a computer simulation of the distillation.

**Table B-2. List of Manufacturers of Evaporation-Type
Equipment Surveyed**

<u>Company</u>	<u>Location</u>	<u>Telephone Number</u>
Advanced Industrial Technology Corp.	Lodi, NJ 07644	(201) 546-5852
APV Company, Inc.	Tonawanda, NY 14150	(716) 692-3000
Aqua-Chem., Inc.	Milwaukee, WI 53201	(414) 962-0100
Artisan Industries, Inc.	Waltham, MA 02254	(617) 893-6800
Blaw-Knox Food & Chemical Equipment, Inc., Buflovak Division	Buffalo, NY 14211	(716) 895-2100
Ecodyne Corp., Unitech Division	Union, NJ 07083	(201) 686-1181
Goslin-Birmingham, Div. of Envirotech	Birmingham, AL 35201	(205) 324-7511
Haveg Industries, Inc.	Wilmington, DE 19808	(302) 995-3800
HPD, Incorporated	Naperville, IL	(312) 357-7330
Joule, Inc.	Edison, NJ	(201) 672-2000
Nooter Corporation	St. Louis, MO 63166	(314) 621-6000
Riley-Beaird, Inc.	Shreveport, LA 71130	(318) 865-6351
Rosenblad Corporation	Princeton, NJ 08540	(690) 452-2626
Wiegand Evaporations, Inc.	Columbia, MD 21045	(301) 997-9500
WSF Industries, Inc.	Buffalo, NY 14217	(800) 874-8265

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

DEFENSE TECHNICAL INFORMATION
CTR

CAMERON STATION 12
ALEXANDRIA VA 22314

DEPT. OF DEFENSE
ATTN: OASD/A&L (EP)
(MR DYCKMAN) 1
WASHINGTON DC 20301-8000

CDR
DEFENSE FUEL SUPPLY CTR
ATTN: DFSC-Q (MR MARTIN) 1
DFSC-DF (MR FRENCH) 1
CAMERON STATION
ALEXANDRIA VA 22304-6160

CDR
DEFENSE GENERAL SUPPLY CTR
ATTN: DGSC-SSM (MR REYNOLDS) 1
ATTN: DGSC-STC (MR DOYLE) 1
RICHMOND VA 23297-5000

DOD
ATTN: DUSDRE (RAT) (DR DIX) 1
ROOM 3-D-1089, PENTAGON
WASHINGTON DC 20301

DEFENSE ADVANCED RES PROJ
AGENCY
DEFENSE SCIENCES OFC 1
1400 WILSON BLVD
ARLINGTON VA 22209

DEPARTMENT OF THE ARMY

CDR
U.S. ARMY BELVOIR RESEARCH,
DEVELOPMENT & ENGINEERING CTR
ATTN: STRBE-VF 10
STRBE-BT 2
FORT BELVOIR VA 22060-5606

HQ, DEPT OF ARMY
ATTN: DALO-TSE (COL BLISS) 1
DALO-TSZ-B (MR KOWALCZYK) 1
DALO-AV 1
SARD-TR (MR APPEL) 1
WASHINGTON DC 20310-0005

CDR
US ARMY MATERIEL COMMAND
ATTN: AMCDE-SS 1
AMCSM-WST 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

CDR
US ARMY TANK-AUTOMOTIVE CMD
ATTN: AMSTA-RG 1
AMSTA-TSL (MR BURG) 1
AMSTA-MTC (MR GAGLIO),
AMSTA-MC, AMSTA-MV 1
AMSTA-RGP (MR RAGGIO) 1
AMSTA-MLF (MR KELLER) 1
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TRACY CA 95376-5051

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CDR
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NEW CUMBERLAND PA 17070

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PETROLEUM & WATER LOGISTICS
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ST LOUIS MO 63120-1798

TRADOC LIAISON OFFICE
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ST LOUIS MO 63120-1798

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ATSM-PFS (MR ELLIOTT) 1
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CDR
US ARMY TRANSPORTATION SCHOOL
ATTN: ATSP-CD-MS (MR HARNET) 1
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U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL AL 35898

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FORT KNOX KY 40121

CDR
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DEVELOPMENT ACTIVITY
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CDR
US ARMY LOGISTICS CTR
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CDR
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ATTN: ATSF-CD 1
FORT SILL OK 73503-5600

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US ARMY ENGINEER SCHOOL
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FORT BELVOIR VA 22060-5606

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US ARMY INFANTRY SCHOOL
ATTN: ATSH-CD-MS-M 1
FORT BENNING GA 31905-5400

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CDR
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ATTN: SGRD-USG-M (MR EATON) 1
FORT DETRICK, MD 21701

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US ARMY TANK-AUTOMOTIVE
COMMAND (TACOM)
WARREN MI 48397

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HQ, US MARINE CORPS
ATTN: LPP 1
LMM/2 1
LMW 1

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US MARINE CORPS DEVELOPMENT
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END

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